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# TECHNICAL NOTES

## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 536

# THE 6-FOOT-4-INCH WIND TUNNEL AT THE

## WASHINGTON NAVY YARD

By G. L. Desmond and J. A. McCrary

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Preface.- Prior to July 1930, this laboratory was
equipped with an 8- by 8-foot closed return-circuit wind
tunnel (reference 1), and a 4- by 4-foot N.P.L.-type tun-
nel. The limitations of the latter together with demands
for increased wind-tunnel testing facilities justified its
replacement by a larger tunnel. Accordingly, the Bureau
of Construction and Repair authorized the construction of
an open-throat enclosed return-passage tunnel embodying
the best available design information and scaled to suit
housing facilities. This new tunnel with a circular jet
of 6-foot-4-inch diameter provides a smooth air stream
capable of a maximum speed of 120 miles per hour. The
tunnel construction was begun in August 1930 and completed
in April 1931. The aerodynamic balance was installed in
September 1932.

The material of this report falls naturally into
three parts. The first part is a description of the tun-
nel and its auxiliary equipment. The second part is a
discussion of the calibration tests which have been car-
ried on since the completion, but interrupted from time to
time for the prosecution of more urgent work. The most
important results of these tests are presented in graphi-
cal form. In conclusion, typical air force and moment
curves are presented for the XPH-1 flying boat and com-
pared with similar results from the 8- by 8-foot wind tun-
nel.

DESCRIPTION OF THE TUNNEL

General.- The 6-foot-4-inch wind tunnel is located on
the second and third floors of the Model Storage Building,
in which the 8- by 8-foot wind tunnel is also housed. A
sectional elevation and the principal dimensions of the
tunnel are given in figure 1.

The air flows from a pressure chamber 12 feet 8 inches
square, accelerates through the converging entrance cone

to form a circular air jet of 6-foot-4-inch diameter, and passes the open test section, a distance of 6 feet 7 inches.  Entering the belled exit cone, whose throat diameter is 6 feet 7-1/4 inches, the air decelerates through the enclosed return passage, completing its circuit on the floor above where the tunnel cross section once more becomes 12 feet 8 inches square.

The tunnel has an over-all length of 56 feet 4 inches, a height of 30 feet, and a maximum width of 12 feet 8 inches.  It is constructed of sheet metal one-sixteenth inch thick, riveted into sections, and stiffened with steel angles.  The sections are bolted together in assembly and supported by steel footings from the floors of the building.  Air leakage is materially reduced by tarred roofing paper in the riveted seams, and felt between the bolted sections.

Test section.- The entrance and exit cones are made of laminated wood, each turned to size in a lathe, and bolted in place.  This construction was of value during calibration tests when alterations were desired.  A wooden platform below the open jet provides easy access to the test section and also serves as a protection for the balance.  A carriage with a vertical member on each side of the air stream is suspended from the ceiling so that it may be moved upstream or downstream.  This facilitates the suspension of test specimens in the air stream which do not require force measurements and which are not suitable for mounting on the aerodynamic balance.

Exit cone.- In the original construction the exit cone was belled from 8-foot diameter to a throat of 6-foot-8-inch diameter (see fig. 2), whence it expanded as a right circular cone in continuance of the return passage. Principally because of the expansion in passing the open test section, the entire air stream could not enter the return passage through the exit cone.  As a result, a "stagnation ring" was formed in the bell and the outer boundary of air deflected making an undesirable spill into the vicinity of the operator.  This exit cone was later replaced, the original 8-foot diameter decreased to 7 feet 3$\frac{1}{2}$ inches, equivalent to the "stagnation ring," and the spill allowed to pass on downstream.

Guide vanes.- As shown in figure 3, guide vanes are placed in the corners of the tunnel to assist in turning the air smoothly.  The vanes immediately upstream from the

entrance cone have the dimensions as given in figure 3.
The vanes in the remaining three corners of the tunnel are
larger and are dimensioned according to figure 4. The cam-
bered surfaces are circular arcs intersecting at the trail-
ing edge and connected at the leading edge by an arc of
small radius.

The vane contours were formed by nailing galvanized
metal sheets to the wooden leading and trailing edges sep-
arated by properly shaped ribs.

Honeycomb.- A honeycomb placed ahead of the entrance
cone served to stabilize the air flow and smooth out pres-
sure surges. It is formed by 16 concentric rings whose
radii increase in intervals of 4-3/4 inches to a maximum
diameter of 12 feet 7 inches. Radial vanes are spot weld-
ed at uniform intervals between the rings, so that the
cells have an approximate area of 17.4 square inches. The
depth of the honeycomb is 24 inches.

Propeller and motor.- The air flow in the tunnel is
generated by a three-blade, adjustable-pitch, aluminum-
alloy propeller designated as Bureau of Aeronautics Design
OS-3. The tips of the original 13-foot diameter propeller
were cut off to a diameter of 10 feet 7½ inches for use in
the tunnel.

The propeller is mounted on a 4-3/4-inch diameter
steel drive shaft, 13 feet 9½ inches long and directly
coupled to the driving motor outside of the tunnel. The
d-c, shunt-wound, interpole-drive motor has a rating of
200 horsepower at 230 volts and 1,200 r.p.m. The Ward
Leonard, or voltage control system, is used for speed reg-
ulation and permits the close adjustment of any desired
air speed within the range of 10 to 120 miles per hour.

Four struts of 3/4- by 6-inch bar steel spaced 90°
apart were originally installed to support the thrust bear-
ing immediately behind the propeller. The propeller blades
whipping past these struts set up pressure pulses that
could be distinctly heard at the higher tunnel speeds,and
could easily be distinguished from the other tunnel noises.
To reduce the noise from this source, the above struts
were replaced by a second set having a cross section of
aerodynamic form but curved away from the propeller as far
as strength considerations permitted. This arrangement,
shown in figure 1, has been found beneficial in reducing
some of the noise of operation.

Air-speed measurement.- A  U.S.N. standard pitot tube,
fastened to the face of the entrance cone and calibrated
to the average dynamic pressure of the test section, is
used in connection with a multiple-tube manometer to de-
termine the air speed.

The manometer is shown at the left in figure 5.
Eight glass tubes are partially imbedded in its sloping
face, their ends terminating in side wells and the side
wells properly connected to the pressure inlets and main
liquid reservoir.  The glass tubes are set at varying
slopes in order to have nearly uniform graduations on the
mile-per-hour scale.  The ends of the tubes overlap to
keep the meniscus of the indicating fluid (alcohol) always
visible.  An adjustable float in the main liquid well pro-
vides an adjustment for zero setting.  The manometer has a
range of 0 to 8.5 inches of water, equivalent to an air-
speed range of 0 to 130 miles per hour.

Attack-angle measurement.- An intense line source of
light, focused through a lens and reflected from a small
mirror on the spindle of the aerodynamic balance to a
ground-glass scale, serves to measure the angle of attack
of airplane and airfoil models.  This method increases the
accuracy of setting over the vernier scale, with which the
balance is equipped, and also permits the compensation of
any bending or deflection that occurs in the balance sys-
tem.

The mirror may be seen projecting through the wind-
shield in figure 6 and the graduated scale is shown on the
underside of the platform near the top center of figure 5.
The mirror consists of five trapezoidal-shaped, plane fac-
ets of polished stainless steel fastened to a steel base
in such manner as to form the concave segment of a prisma-
toidal surface.  This assembly is clamped to the balance
spindle and rotates with the test specimen about the moment
axis when the angle of attack is changed.  When the normal
median plane of a facet is vertically above the center of
rotation, the incident light beam is reflected downward
in the vertical plane to the ground-glass scale.  Rotating
the mirror changes the incidence angle of the light beam
with a resultant shift in the reflected image on the scale.
With $5^\circ$ rotation from the center position, the light beam
is intercepted by the matched edges of an adjoining facet
to form two images, one image leaving, and the other enter-
ing the scale.  Each facet has a range of $10^\circ$ rotation and
the mirror has a total range of $50^\circ$.

## THE AERODYNAMIC BALANCE

General.- The aerodynamic balance for the 6-foot-4-inch wind tunnel is a modification of the 6-component balance now in use in the 8- by 8-foot wind tunnel. The continued satisfactory working of the original balance since its installation in 1921, together with its ease of operation, adaptability to airplane-model testing, and accuracy of measurements, was sufficient evidence that a similar type balance would be desirable for the new wind tunnel. The new balance maintains the working principles of the original balance. The test specimen, however, is supported above the weighing mechanism instead of below it as in the case of the balance of the 8- by 8-foot tunnel. Only a brief description of the balance structure will be given here as a detailed discussion of the original balance may be found in reference 2.

The weighing mechanism of the balance is shown photographically in figure 5. The steel tube penetrating the platform at the top of the picture is the spindle, and carries the model as shown in figure 6. The windshield surrounding the spindle is made to the Navy No. II strut section, and reduces the tare forces of the balance to about 10 percent of the minimum drag of an average airplane model. A sectional elevation of the balance in figure 7 shows the important working parts.

Force system.- A steel frame mounted on four elastic steel posts is capable of very nearly frictionless motion in any direction in a horizontal plane. This motion is constrained, however, to provide horizontal translation in one direction, which motion, when connected through a bell-crank system to a weighing beam, provides for measurement of drag forces. There is no provision for the measurement of side drag forces since the necessity of such measurement is too infrequent, and they may be obtained on the balance of the 8- by 8-foot tunnel when needed. However, a side drag weighing mechanism could easily be installed on the new balance should it become necessary.

A lift tube is supported vertically at the center of the floating frame through elastic knife-edges to a properly counterbalanced weighing beam. The lift pipe is guided in frictionless vertical translation by horizontal, taut, elastic steel rods. These rods also serve to transmit any horizontal translation of the lift tube to the

floating frame.  The lift and drag weighing beams are set
above the surface of an all-metal table which surrounds
the floating frame.

Moment system.- Inside of, and supported by, the up-
per end of the lift tube, is a close-fitting steel yaw
tube.  At the point of support, a worm gear, with a mi-
crometer head, engaging a worm wheel on the yaw tube,
serves to rotate the yaw tube, and eventually the test
specimen, through any desired angle of yaw.  Inside of
the yaw tube, a third or center tube is supported as a
frictionless torsional pendulum.  A taut, steel wire,
0.135-inch diameter, anchored within, and coaxial with
the center tube, is firmly grasped at its mid-point by a
transverse bridge bar securely seated in the yaw tube.
The anchors for this wire are of sufficient size to ac-
commodate hardened, steel inserts.  Four radial knife-
edges, 90° apart, at each end of the yaw tube, press
against these inserts at the axis of the center tube and
hold it coaxial with the yaw tube.  In this manner, the
center tube pivots without friction relative to the yaw
tube.  This movement, however, is constrained and trans-
mitted through a bell-crank linkage to the yawing moment
weighing beam.

The center tube extends above the weighing beams into
the air stream of the tunnel.  A machined steel shank,
fitted into the end of the center tube carries a pulley
wheel in conjunction with a dovetail fitting for holding
the test specimen.  This pulley is mounted on an elastic
knife-edge.  Pitching moments about this knife-edge are
transferred by a taut, steel belt to a weighing beam below,
also mounted on elastic knife-edges.  A worm sector and
gear with a micrometer head in the belt-and-pulley system
provides for pitching the test specimen in the air stream
to any desired attitude.  The moment weighing system, in-
cluding the beam, is assembled on the upper end of the
center tube as a separate unit and may be removed from the
balance with ease, leaving the air stream clear for tests
not requiring the use of the balance.

All forces and moments are weighed on beams vibrating
between electric contact stops at the beam ends.  The con-
tacts energize the 1/200 horsepower motors used in driving
the rider weights to balance positions.  The movement be-
tween the stops never exceeds 0.003 inch, which movement
when transferred to the floating members of the balance
reduces to the order of 0.0006 inch as a maximum, and fixes

the displacements and resultant friction losses as negligible quantities. A micrometer disk at the end of each beam, together with graduations on the beam, make it possible to record forces to 0.001 pound and moments to 0.001 pound-inch. The balance is supported on a steel structure independent of the surrounding building. This leaves the balance free from vibrations of the building and improves its performance greatly.

## CALIBRATION TESTS

General.- A transverse central area, 4 feet square, at the model test location, 2 feet 5 inches downstream from the entrance cone, was carefully surveyed for pressure distribution and for angularity of the air stream. Wire mesh properly located on the upstream side of the honeycomb served to bring the dynamic pressure distribution over the reference area within ±1 percent of the mean value at 40 miles per hour. The static pressure amounted to 1.5 percent of the dynamic pressure and decreased slightly at the outer boundaries of the transverse reference area. The wind direction was within ±0.2° of level. Measurements of the wind direction in yaw were not obtained. Surveys at stations upstream and downstream from the reference area, and at different air speeds, showed the above flow conditions to hold within desirable limits.

Operating characteristics.- Measurements of the power input and speed of the drive motor were made for the air-speed range of the tunnel. These quantities are plotted in figure 7, together with the calculated horsepower of the air stream at the test section and the resultant conventional energy ratio. The horsepower input to the drive motor was calculated from the voltmeter and ammeter readings for the several air speeds. Data and facilities were not available for calculating the motor efficiency, and this factor is not included in the derived energy ratio.

The energy ratio at the usual test air speed of 40 miles per hour, is 1.28. The maximum energy ratio of 1.56 occurs at the maximum air speed of 120 miles per hour. Before the installation of the honeycomb, this maximum ratio was 1.75. The comparatively low value of this ratio is due in part to the propeller, the blades of which were set at a pitch angle to load the drive motor to rated capacity. In consequence, the pitch angle is well below the value for best efficiency.

Pulsations and bleeder holes.- After reducing the
bell on the exit cone (see p. 3), violent pulsation devel-
oped at critical air speeds of 30 and 55 miles per hour,
and at all speeds above 85 miles per hour.  The division
of the outer air boundary at the lip of the exit cone was
unstable, and the resultant alternate inflow and spill
caused periodic pressure pulses that came into resonance
with the tunnel structure at these air speeds.

As a first trial at damping the pulsations, 10 open-
ings, each 4 by 8 inches, were cut in the return passage
11 feet downstream from the exit cone.  These were distinct-
ly beneficial, and increasing the number of openings to 20,
eliminated the severe pulsations.  Some minor vibrations
and pulsations remained but their origin could be traced
to the tunnel structure.  These were eliminated by install-
ing tie rods at vital points and by fastening wood lagging
to the large flat surfaces of the pressure chamber.

Static pressure gradient downstream.- The downstream
static pressure gradient, measured on the center line, was
adjusted to within desirable limits after several changes
of the entrance and exit cones.  The results for ten dif-
ferent entrance- and exit-cone conditions are shown in fig-
ure 2, in as nearly self-explanatory manner as possible.
Condition I shows the gradient of the original tunnel, in
which there was no flare on the entrance cone, and the exit
cone had the large bell previously noted.  As a first trial
to improve this gradient, a flare was formed of wooden ribs
covered with cardboard and fastened to the face of the en-
trance cone (condition II).  In the remaining tests the
flare was formed by working out the interior surface at
the mouth of the entrance cone to a template.  A decrease
in the exit-cone throat diameter was accomplished by fas-
tening wooden bands in the throat.  These bands were faired
as well as possible to eliminate undue disturbance.

From the results, it may be seen that the flare on
the entrance cone affects the pressure gradient consider-
ably, the effect reaching with decreasing magnitude to the
exit cone.  Condition X is a graph of the pressure gradient
existing in the present calibration.  It was considered
satisfactory because the variation over a normal model
length is within ±0.5 percent of the dynamic pressure, and
the air flow is smooth.  Conditions II, III, and IV show a
lower pressure at the entrance cone, but this was obtained
at the expense of a noticeably rough boundary layer.  The
same pressure reduction could probably be accomplished with

smoother flow if the length of the flare along stream were increased. This was not possible without decreasing the length of the open jet or cutting into the entrance cone farther than desired.

Conditions VI, VII, and VIII show that a decrease in area of the exit cone lowers the static pressure at the exit cone slightly. Further, this effect carries only to about midway of the test section and does not change the pressure at the entrance cone.

The drop in static pressure near the exit cone in conditions IX and X, as compared to prior conditions, was a result of cutting the bleeder holes in the return passage. An earlier survey of the return passage had shown an abnormal pressure rise from the exit cone to the first set of guide vanes. Apparently the air was being dammed at this point. The bleeder holes permitted a pressure relief but did not eliminate the air damming at the vanes. In order to do this, a relocation of the vanes would be necessary.

## XPH-1 FLYING-BOAT TESTS

General.- The agreement of results for several airfoil and airplane models tested in the 6-foot-4-inch wind tunnel and in the 8- by 8-foot wind tunnel was sufficiently close to permit routine testing to be undertaken. Accordingly, the XPH-1 flying boat was given a complete routine test in pitch and yaw. The lift, drag, and pitching-moment curves from this test for neutral elevator are plotted in figures 9 and 10', in comparison with a similar test in the 8- by 8-foot tunnel. These results have not been corrected for tunnel-wall interference as such corrections are never applied to ordinary airplane-model tests, and it is thought that the comparison of measured forces are the most desirable. An exemplary plot of these corrections to drag are shown in figure 10, and their application brings the lift vs. drag curves into good agreement.

The pitching-moment curve from the 6-foot-4-inch tunnel, shown in figure 9, indicates static instability in the attack-angle range of $-8°$ to $-3°$. This condition was contradictory to full-scale performance, and it was further disproved in the 8- by 8-foot tunnel test. In addition, the latter test shows a better stability throughout

the entire test range.  Such a condition is expected in
comparing results from open-throat and closed-throat tun-
nels, but the difference in this case exceeds the expecta-
tion sufficiently to indicate an external deficiency in
the operation of the 6-foot-4-inch tunnel.  A careful study
of the possible discrepancies disclosed two major consider-
ations.  This difference could be due to the turbulence of
the air stream as it affected the flow around the hull of
the flying boat, or to an interference from the windshield
of the balance spindle.  Both of these possibilities were
investigated.

   Turbulence.- The drag of a 5-inch diameter brass
sphere was used as an index of turbulence of the air flow
in the two tunnels.  For drag measurement, the sphere was
supported on a streamlined clip fastened to the spindle of
the aerodynamic balance.  The tare drag of the clip was
measured with the sphere suspended in close proximity to,
but not touching, the clip.  It has been shown by tests
(reference 3) that supporting the sphere in the above man-
ner introduces an interference in the boundary layer in
such manner as to increase the drag of the sphere.  An at-
tempt was made to approximate this interference drag by
placing a dummy clip above but not touching the sphere,
thereby doubling the interference.  The drag coefficients
of the sphere calculated from test data thus obtained are
plotted against Reynolds Number in figure 11.  Using the
drag coefficient of 0.3 as a criterion, the critical
Reynolds Number of the 6-foot-4-inch wind tunnel is $R_c =$
295,000, and the corresponding value in the 8- by 8-foot
tunnel is $R_c = 210,000$.  These values are subject to a
small error because of the method of support, but the com-
parison between the two tunnels is thought to be reliable.
The high value of $R_c$ in the 6-foot-4-inch tunnel, indi-
cating comparatively smooth air flow, was confirmed by the
abrupt break in lift at the burble of an airplane or air-
foil model.

   Two methods were used to increase the turbulence in
the 6-foot-4-inch tunnel.  In the first case, a grating of
strings of 0.06-inch diameter and spaced one half inch
apart was stretched horizontally across the air stream at
the entrance cone.  In the second case, a wire screen of
0.105-inch-diameter wire and 1-1/4-inch mesh was placed
about 6 inches inside the entrance cone.  The turbulence
of the air stream as indicated by the sphere drag (fig. 11)
was thus increased to equal the turbulence of the 8- by
8-foot tunnel.

Force tests were made on the XPH-1 flying boat for each of the above conditions, and the results are plotted in comparison with the original values in figure 9. The drag of the model was decreased in the attack-angle range of $-8°$ to $-3°$, but it remained unaffected for the remainder of the test range. The slope of the lift curve and the maximum lift of the model were both increased. The sharp break in lift at the burble was also diminished. These changes in forces, however, failed to change the pitching moments except in the negative range in question. Here the previous instability was improved to a neutral stability, indicating that the divergence of the original results was due in part to a difference in flow conditions.

Although the sphere drag tests indicated that the turbulence of the 6-foot-4-inch tunnel was increased to closely approximate that of the 8- by 8-foot tunnel, the lift curve of the XPH-1 flying boat indicates a greater turbulence effect by use of the string grating than by use of the wire screen. From this it would seem that the sphere measures a "resultant" turbulence that is not completely defined. In addition to a component of magnitude, turbulence may have a component of a dimension which is the "coarseness" or "fineness" of the turbulence grain, and this component is effective in the air flow about a body. No means are available as yet for the complete measurement of turbulence..

Spindle interference.- Because the pitching-moment curves from the two tunnels did not have the same slope, yet the lift and drag forces agreed within the limits of tunnel-wall corrections, it was assumed that the horizontal tail surfaces were being deprived of their full lifting effort by an adverse air flow induced by the windshield of the balance spindle. This was proved by mounting an airfoil on the balance in such manner that the angle of attack could be kept constant and the airfoil rotated through each of the regions traversed by the wings and the tail surfaces of the flying boat. In both cases the lift of the airfoil decreased as its position shifted to correspond to an increase in attack angle of the flying boat. The percentage decrease in lift at the normal wing position was relatively small and not serious, but in the case of the tail-surface position, this decrease was appreciable.

Wind-direction surveys with a yaw head in the vicinity of the windshield showed that the wash over the un-

shielded spindle was only slightly better than with the
windshield in place. End plates proved of no value in de-
stroying the wash unless the plate was quite large. Under
these circumstances the model was subjected to an inter-
ference by its proximity to the large plate. Finally, the
shield was made as neat and as small as the movement of
the model permitted. A small vane, 4 by 12 inches, was
fastened to the top rear of the windshield and tilted to
the air stream to form a counteracting up-wash. The in-
clination of this vane was determined by the condition of
constant lift on the previously mentioned airfoil for all
positions.

In addition, three vanes of sheet metal, 2 by 8 feet,
were hinged on the honeycomb and adjusted until the aver-
age wind direction forward of the windshield was within
±0.2° to level.

The results of a test on the XPH-1 flying boat under
these corrected conditions are shown in figure 10, and the
force and moment plots from the two tunnels now show good
agreement.

## CONCLUSIONS

The 6-foot-4-inch wind tunnel and its auxiliary equip-
ment has proven itself capable of a continuous and reliable
output of data. The real value of the tunnel will increase
as experience is gained in checking the observed tunnel
performance against full-scale performance. Such has been
the case of the 8- by 8-foot tunnel, and for that reason
the comparisons in the calibration tests have been present-
ed.

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# REFERENCES

1.  Zahm, A. F., and Smith, R. E.:  Drag of Two N.P.L.
    Airship Models.  Report No. 206, Construction De-
    partment, Navy Yard, Washington, D. C., 1922.

2.  Zahm, A. F.:  The Six-Component Wind Balance.  Report
    No. 180, Construction Department, Navy Yard, Wash-
    ington, D. C., 1921.

3.  Flachsbart, O.:  Recent Researches on the Air Resist-
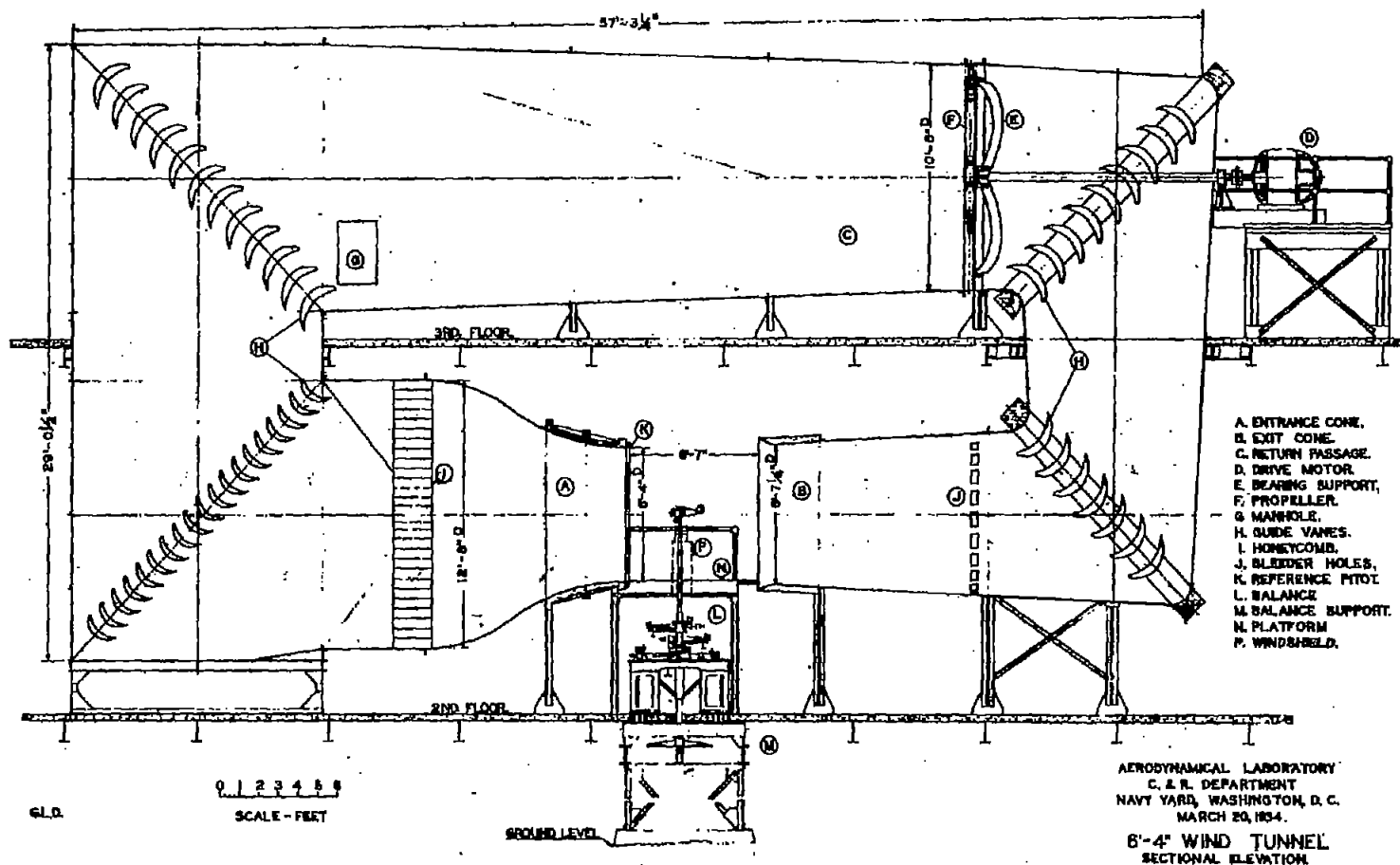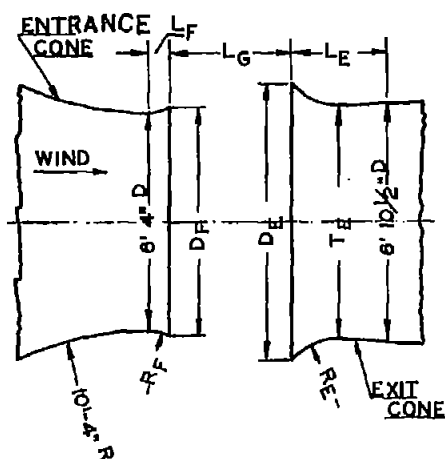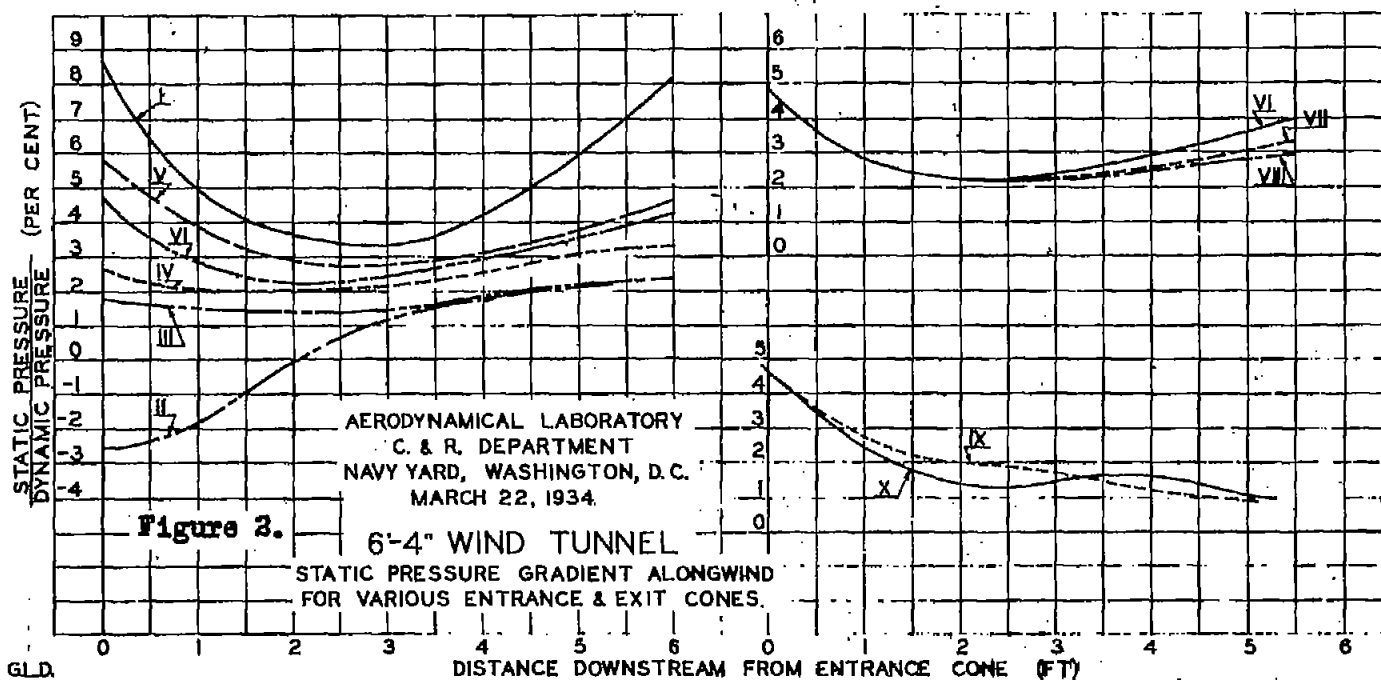    ance of Spheres.  T.M. No. 475, N.A.C.A., 1928.

Fig. 1



A. ENTRANCE CONE.
B. EXIT CONE.
C. RETURN PASSAGE.
D. DRIVE MOTOR.
E. BEARING SUPPORT.
F. PROPELLER.
G. MANHOLE.
H. GUIDE VANES.
I. HONEYCOMB.
J. BLEEDER HOLES.
K. REFERENCE PITOT.
L. BALANCE
M. BALANCE SUPPORT.
N. PLATFORM
P. WINDSHIELD.

AERODYNAMICAL LABORATORY
C. & R. DEPARTMENT
NAVY YARD, WASHINGTON, D. C.
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6'-4" WIND TUNNEL
SECTIONAL ELEVATION.

SCALE - FEET

GROUND LEVEL

3RD. FLOOR

2ND. FLOOR

G.L.D.

Figure 1.

TABLE OF DIMENSIONS.

| COND NO. | ENT. CONE | | | EXIT CONE | | | | GAP | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| | $D_F$ | $R_F$ | $L_F$ | $D_E$ | $T_E$ | $R_E$ | $L_E$ | $L_G$ | |
| I | 6'-4" | 0 | 0 | 8'0" | 6'-8" | 2'-0" | 3'-0" | 6'-10½" | ORIGINAL DESIGN |
| II | 6'-5⅞ | 1'-6" | 5" | 7'-3" | 6'-8" | 2'-0" | 2'6¾ | 6'8¾ | |
| III | 6'-4¾ | FAIRED | 4" | 7'-3' | 6-6½" | 2'-0" | 2'6¾ | 7'3¾ | |
| IV | 6'-4¾ | FAIRED | 6" | 7'-3" | 6'6½ | 2'-0" | 2'6¾ | 7'-1¾ | ENT. CONE FLARED |
| V | 6'4¼ | ∞ | 4" | 7'-3" | 6'6½ | 2'-0" | 2'6¾ | 7'3¾ | |
| VI | 6'4⅜ | 3'0" | 4" | 7'-3" | 6'-8" | 2'-0" | 2'6¾ | 7'3¾ | |
| VII | 6'4⅜ | 3'-0" | 4" | 7'-3" | 6'6½ | 2'-0" | 2'6¾ | 7'3¾ | EXIT CONE THROAT DIAMETER DECREASED. |
| VIII | 6'4⅜ | 3'0" | 4" | 7'-3" | 6'-5" | 2'-0" | 2'6¾ | 7'3¾ | |
| IX | 6'4⅞ | ∞ | 6" | 7'3½ | 6'-7¼ | 1'-6" | 3'-1" | 6'-7" | BLEEDER HOLES IN RETURN PASS. NEW EXIT CONE. |
| X | 6'4⁹⁄₁₆ | ∞ | 9" | 7'3½ | 6'-7¼ | 1'-6" | 3'-1" | 6'-7" | EXISTING CONDITION. |

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Figure 2.

6'-4" WIND TUNNEL

STATIC PRESSURE GRADIENT ALONGWIND
FOR VARIOUS ENTRANCE & EXIT CONES.

STATIC PRESSURE / DYNAMIC PRESSURE (PER CENT)

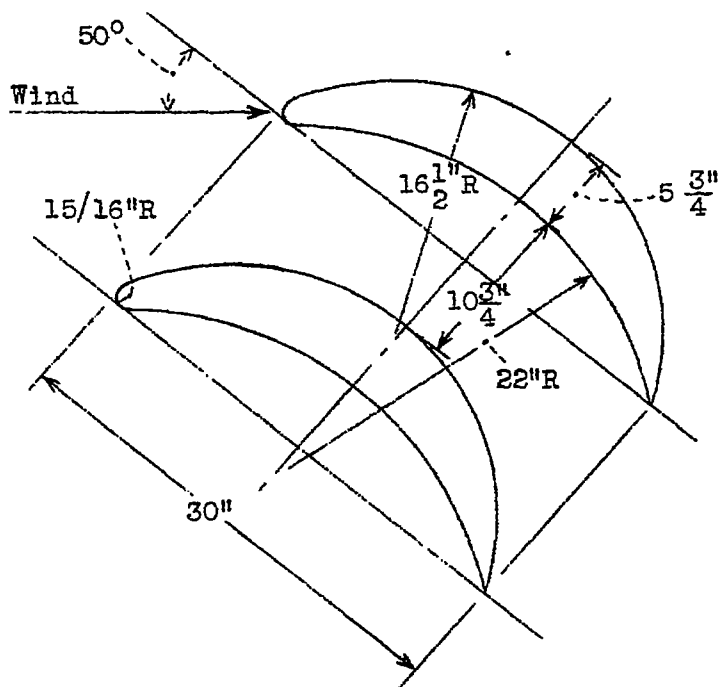DISTANCE DOWNSTREAM FROM ENTRANCE CONE (FT)

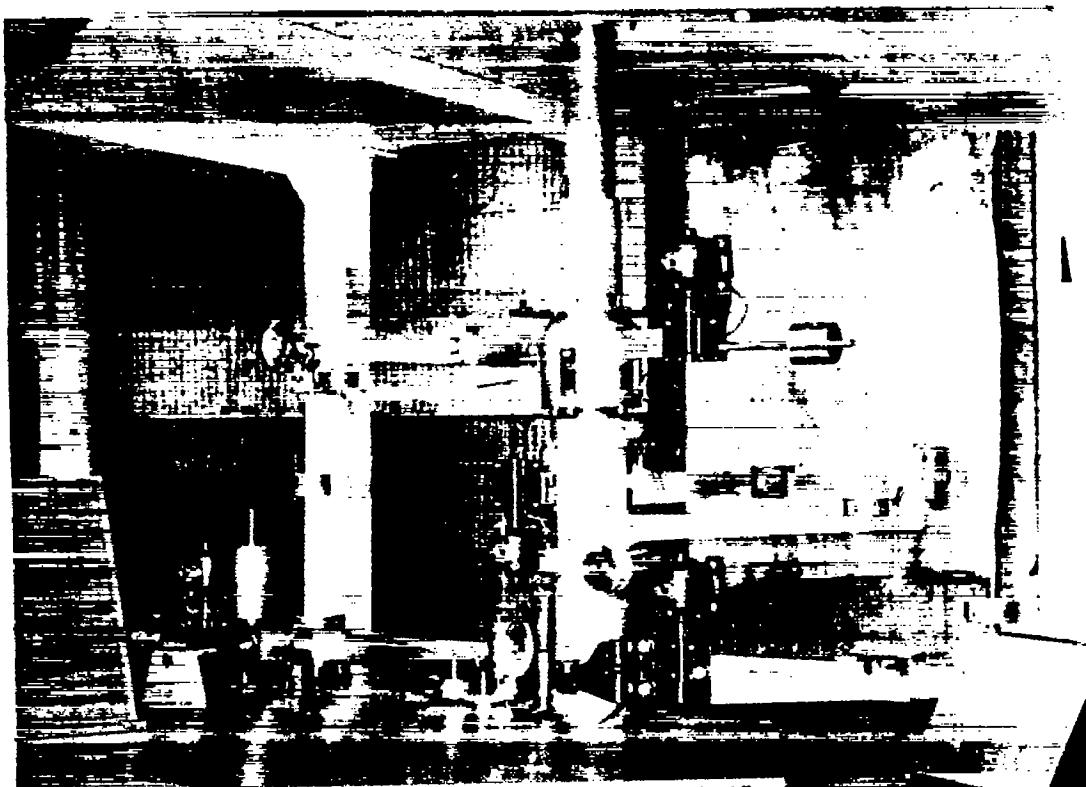Fig. 2
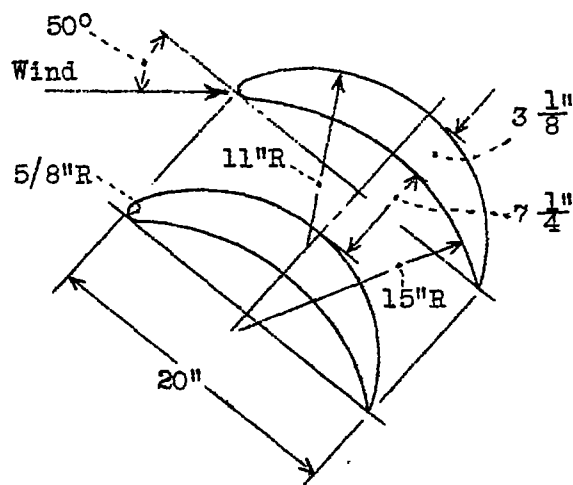
Figure 3.



Figure 4.

Figure 5.- Aerodynamical balance of the 6'-4"
wind tunnel.



Figure 6.- Test section of the 6'-4" wind tunnel.

Fig.7

AERODYNAMICAL LABORATORY
C. & R. DEPARTMENT
NAVY YARD    WASHINGTON, D.C.
JAN. 14, 1934.

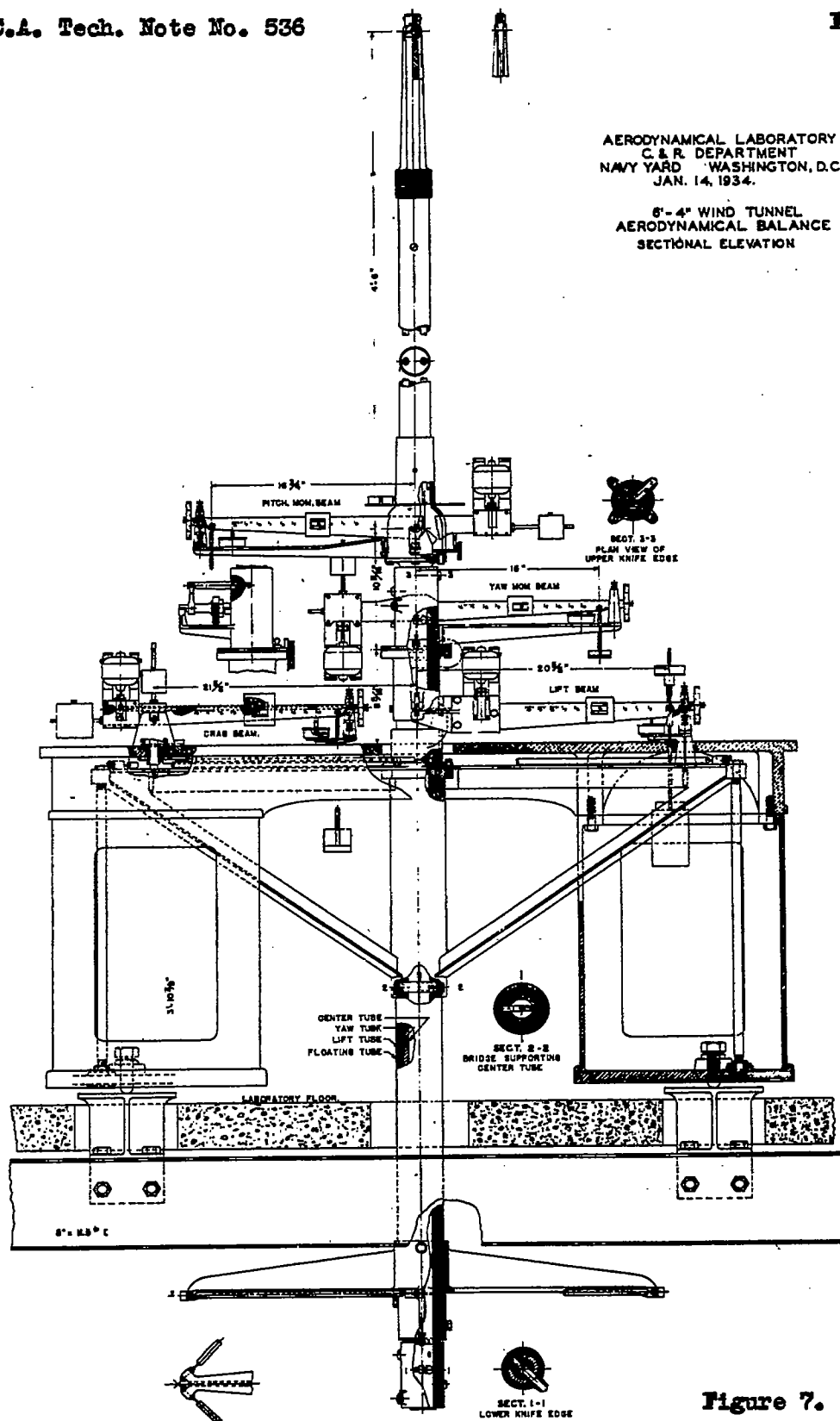8'- 4" WIND TUNNEL
AERODYNAMICAL BALANCE
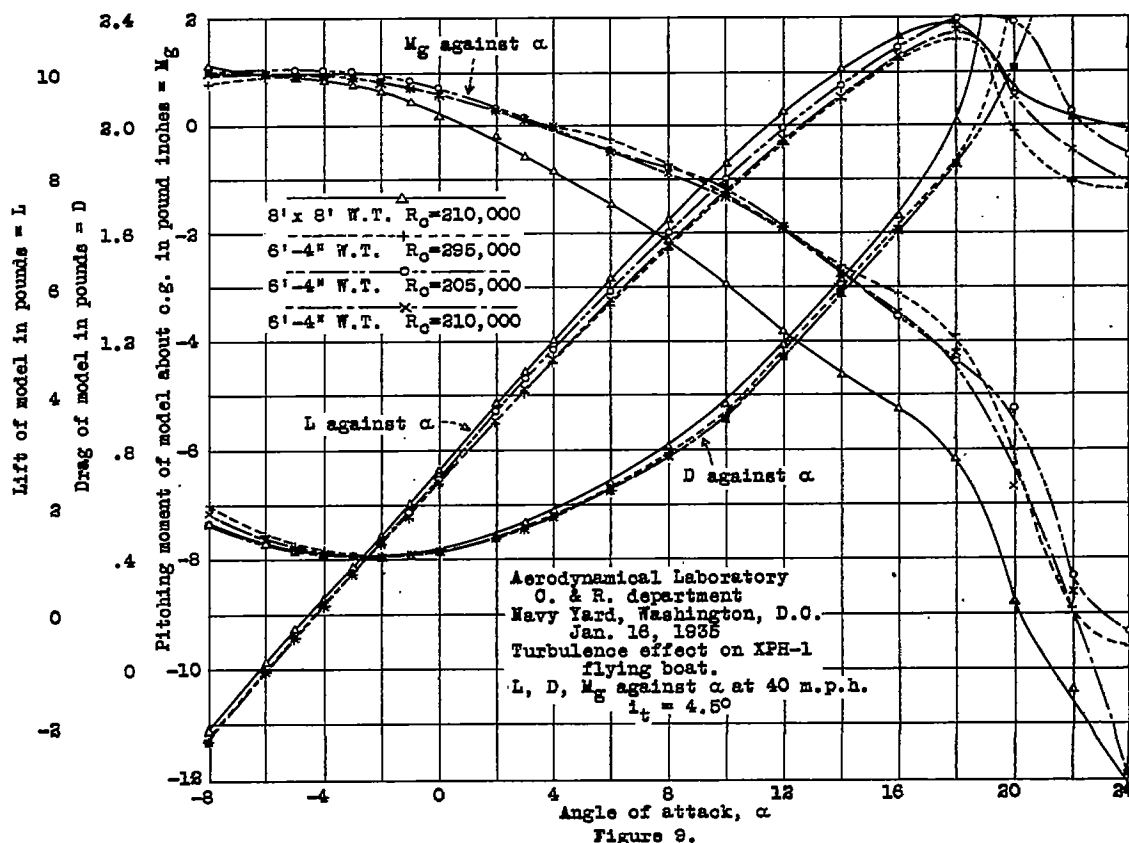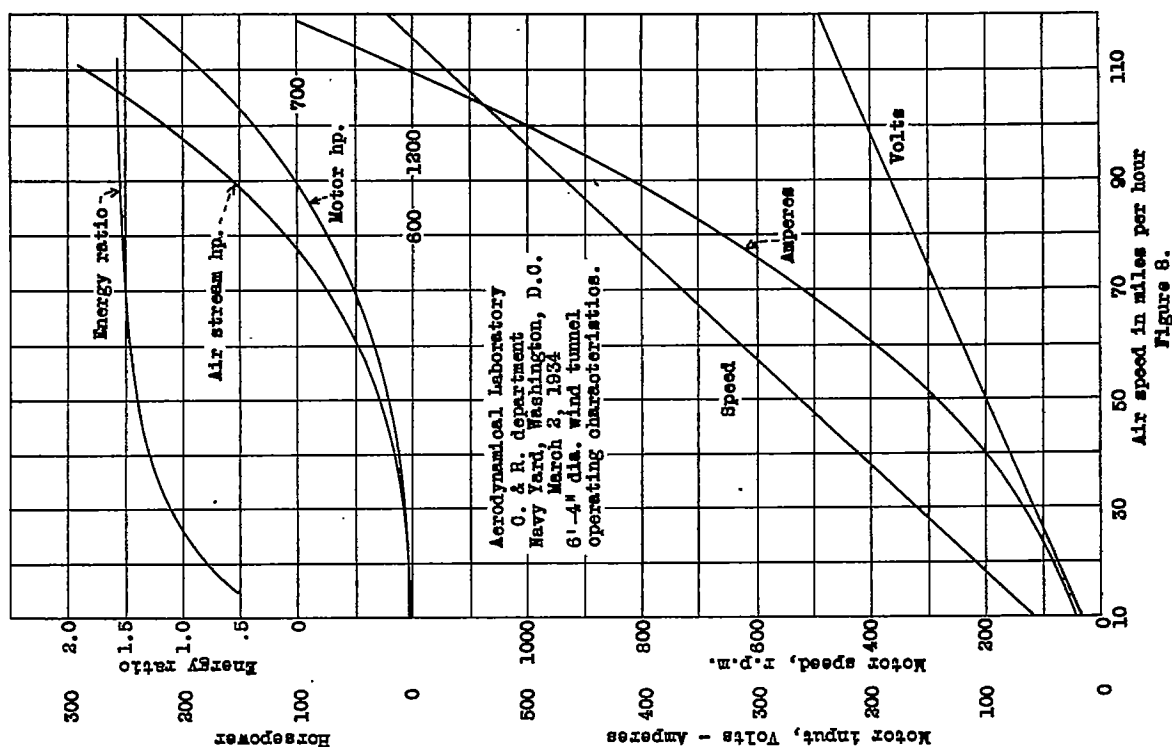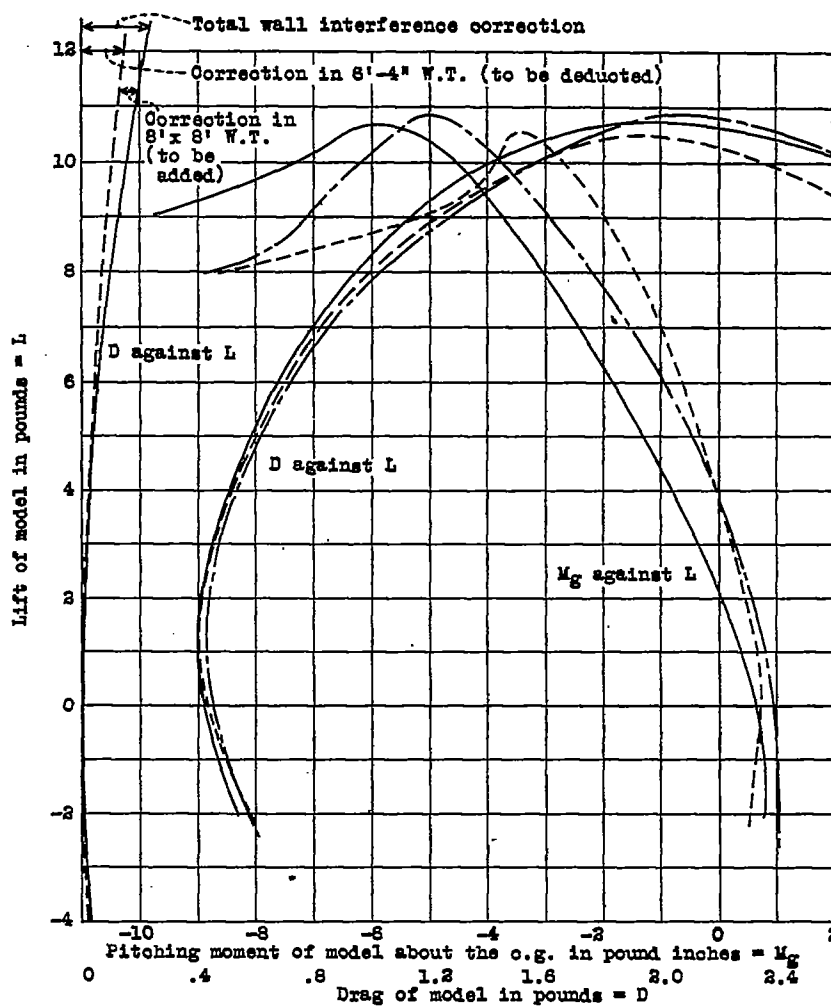SECTIONAL ELEVATION

Figure 7.

Aerodynamical Laboratory
C. & R. department
Navy Yard, Washington, D.C.
March 3, 1934
6'-4" dia. wind tunnel
operating characteristics.

Figure 8.



Aerodynamical Laboratory
C. & R. department
Navy Yard, Washington, D.C.
Jan. 16, 1935
Turbulence effect on XPH-1
flying boat.
L, D, $M_g$ against $\alpha$ at 40 m.p.h.
$i_t = 4.5°$

8' x 8' W.T.  $R_o$=210,000
6'-4" W.T.  $R_o$=295,000
6'-4" W.T.  $R_o$=205,000
6'-4" W.T.  $R_o$=210,000

$M_g$ against $\alpha$

L against $\alpha$

D against $\alpha$

Angle of attack, $\alpha$

Figure 9.

Figure 10.



Figure 11.